InSight Surface Operations: Reducing Cost and Risk Using Integrated Planning, Sequencing and Modeling in APGen

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Outline

- Overview of NASA JPL InSight mission
- Science Planning overview
- Introduction to InSight planning software
- Discussion of previous similar Mars missions
- Comparison to software across Mars missions
- Conclusion

InSight Mission Overview

- Mars lander mission, launched in May 2018 and landing in November 2018
- Equipped with a seismometer, heat probe, weather station and robotic arm
- Primary mission is to determine the composition and size of the core, mantle and crust of Mars, as well as the precession and nutation of the axis of Mars
- Medium budget mission with several overseas partners

Activity Planning on InSight

- Several complicated tasks are required by InSight after landing on Mars, including:
  - Site selection for the instruments
  - Taking hundreds of images
  - Placing the seismometer, its wind and thermal shield, and the heat probe on the surface of Mars
  - Tilt measurements and calibrations
  - Sending back large quantities of data to Earth with very low bandwidth (10-20 megabytes per day)

Activity Planning on InSight (cont.)

- Due to thermal and timing constraints for activities and the low bandwidth, activities need to be prioritized and carefully placed throughout a given day
- This is done through daily activity planning, which is done on a strict timeline of 8-10 hours during instrument deployment (first 90 days on Mars)
- During science monitoring, planning is done on a weekly basis

Activity Planning on Similar Missions

- All JPL surface missions require some amount of activity planning, often with more complex activities and constraints than on InSight
- Phoenix Lander
  - The Mars Phoenix lander shared a design with InSight, and had daily planning for the duration of the mission
  - Daily activity planning took place on a 16-hour timeline, twice as long as on InSight

Activity Planning on Similar Missions (cont.)

- Mars rover missions also require daily activity planning, which is done using similar software to InSight
- MER (Mars Exploration Rover)
  - 16 hour daily tactical timeline at landing, but decreased to 8 hours after years of operations
- MSL (Mars Science Laboratory)
  - Also had a 16 hour daily tactical timeline at landing, decreasing to 8 hours later in the mission

Planning Software Across JPL Missions

- Software on each of the four missions (InSight, Phoenix, MER, and MSL), have several basic functional requirements:
  - Timeline view of activity plan
  - Spreadsheet/table view of activity plan
  - Modeling of data, power, duration and temperature
  - Resource view of modeling results
  - Command sequence generation
- Each mission designs their own software to meet these requirements

InSight Planning Software

- InSight uses four pieces of software for activity planning:
- APGen (Activity Plan Generator)
  - Data, power, thermal and duration modeling
  - Command sequence generation
- SPImaster (Science Plan Integration master)
  - Creating and modifying activity plans
  - Orchestrating APGen modeling in batch mode and displaying the results

InSight Planning Software (cont.)

- RAVEN (Resource And Visualization EngiNe)
  - Viewing activity plan and resource usage after APGen modeling
  - Sharing model results with overseas teams
- Simulation Reports
  - HTML summary of modeling results, constraint violations, command sequence lists, and activity plan durations

InSight Software Requirements

- Timeline view
  - SPImaster, RAVEN
- Spreadsheet/table view
  - SPImaster
- Modeling of resources
  - APGen
- Resource view
  - RAVEN, Simulation Reports
- Command sequence generation
  - APGen

Phoenix Software Requirements

- Timeline view
  - PSI (Phoenix Science Interface)
- Spreadsheet/table view
  - PSI
- Modeling of resources
  - APGen
- Resource view
  - PSI, APGen
- Command sequence generation
  - Excel, helper scripts

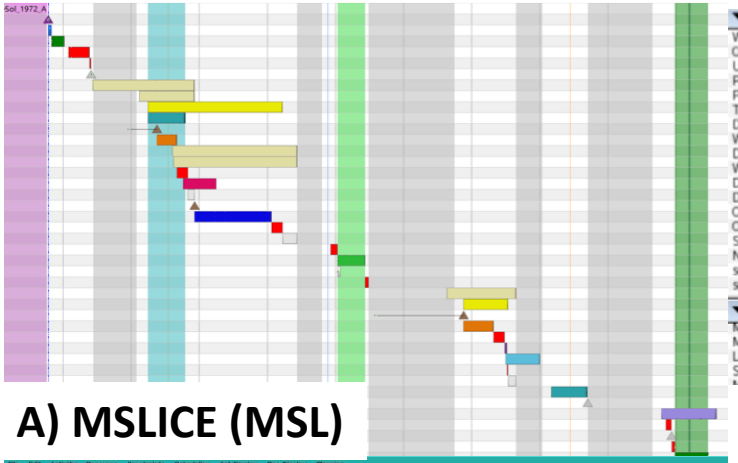
MER Software Requirements

- Timeline view
  - Maestro, MAPGEN (MER APGen)
- Spreadsheet/table view
  - Maestro, Excel
- Modeling of resources
  - MAPGEN
- Resource view
  - MAPGEN
- Command sequence generation
  - MAPGEN, Excel, helper scripts

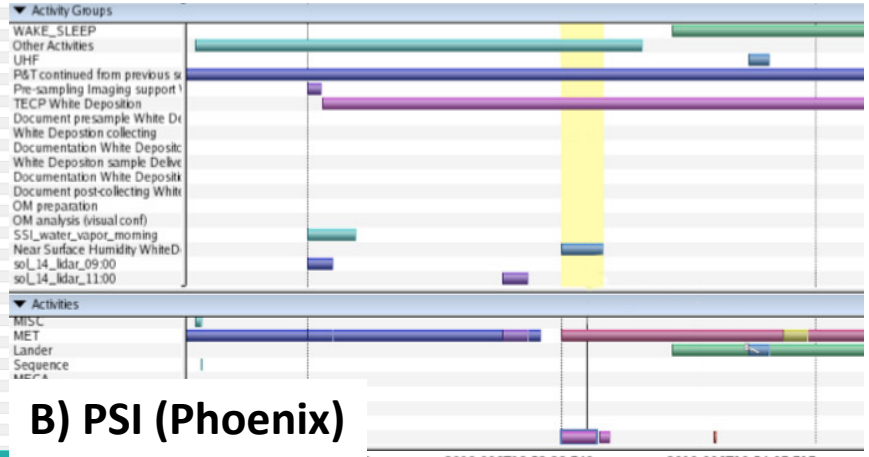
MSL Software Requirements

- Timeline view
  - MSLICE (MSL Interface)
- Spreadsheet/table view
  - MSLICE
- Modeling of resources
  - MSLICE
- Resource view
  - MSLICE
- Command sequence generation
  - MSLICE, helper scripts

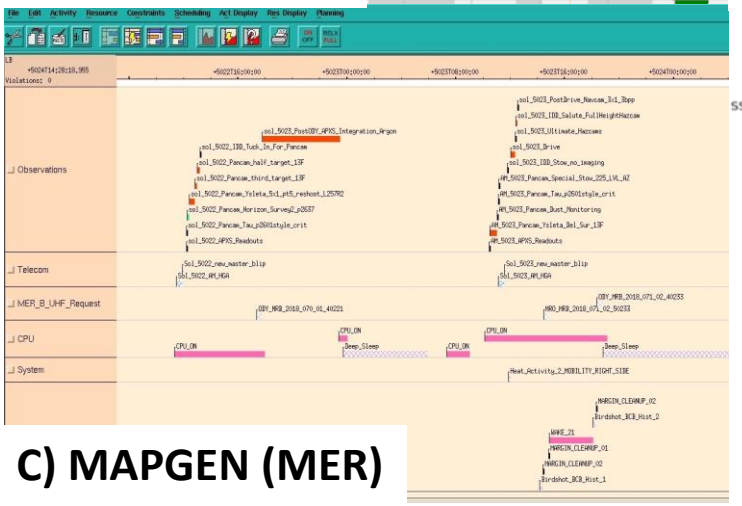
Timeline Views for Each Mission



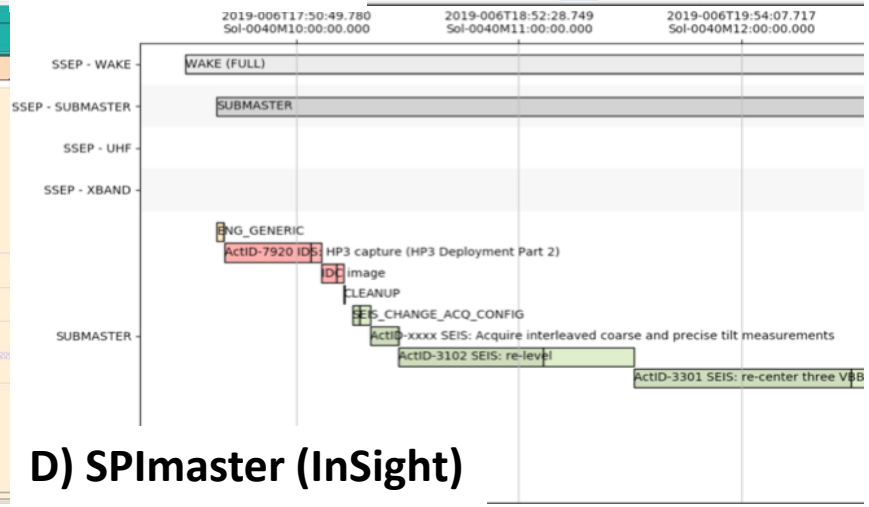
A) MSLICE (MSL)



B) PSI (Phoenix)

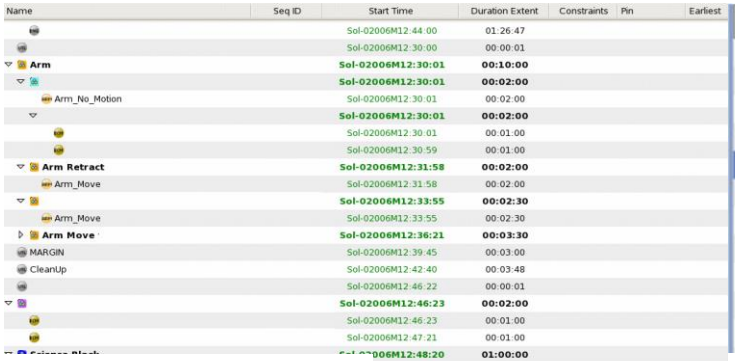


C) MAPGEN (MER)

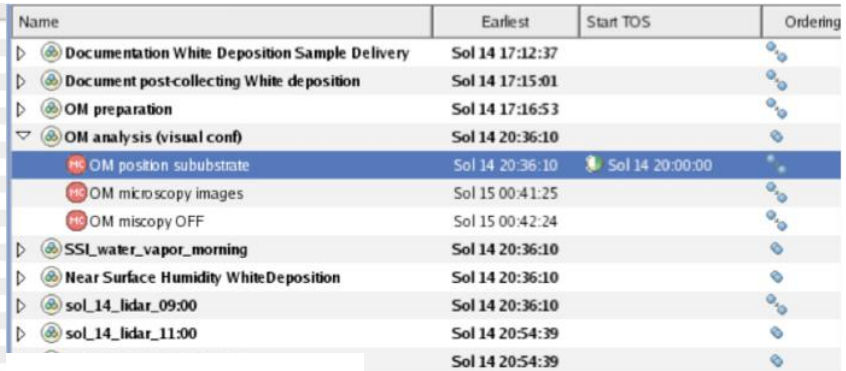


D) SPImaster (InSight)

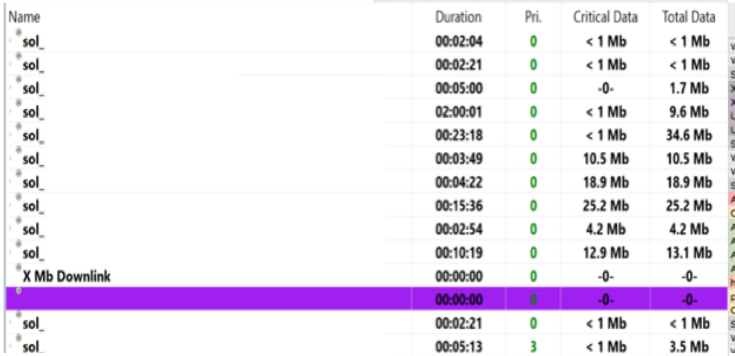
Table Views for Each Mission



A) MSLICE (MSL)



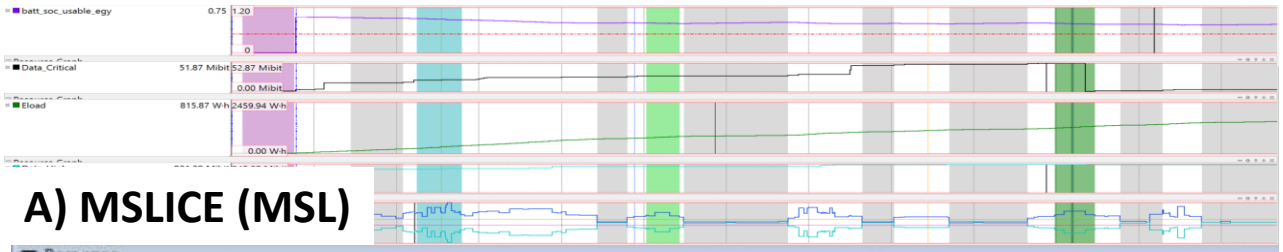
B) PSI (Phoenix)



C) Maestro (MER)

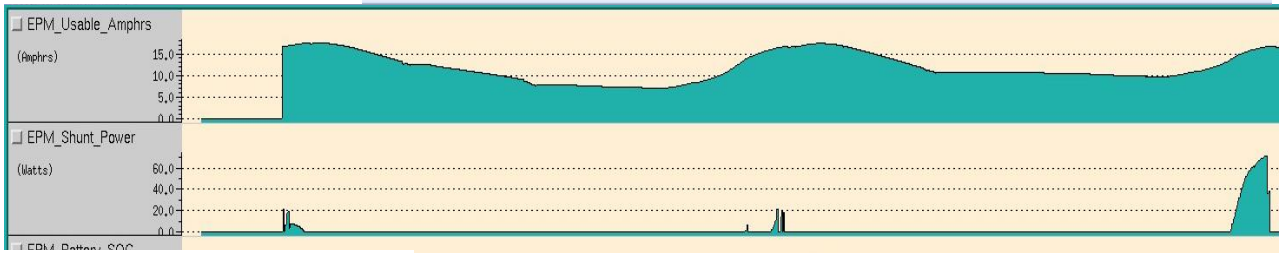
D) SPImaster (InSight)

Resource Views for Each Mission

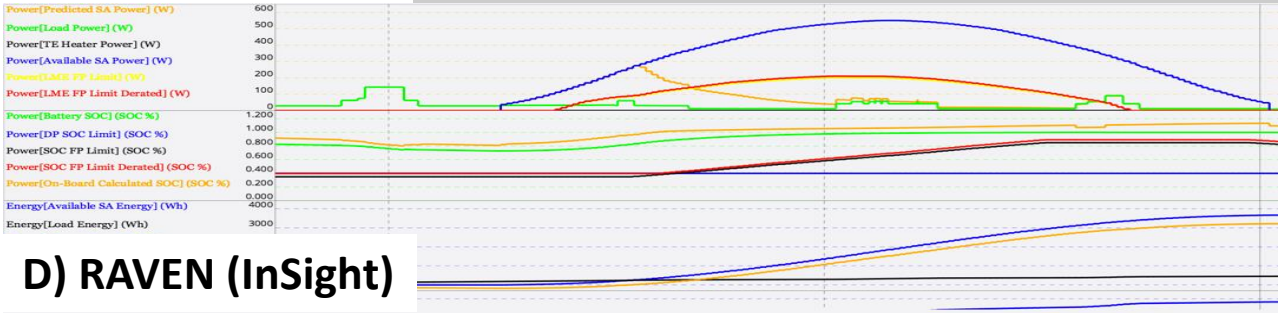


A) MSLICE (MSL)

B) PSI (Phoenix)



C) MAPGEN (MER)



D) RAVEN (InSight)

Cost Comparison of Planning Software

- Despite each mission having roughly the same basic features in their planning software, the development costs vary significantly
- The cost estimates are only including work done at JPL, and details are included in backup slides

Mission	Software	Relative Development Cost (MSL Prime = 1)
InSight	SPImaster/APGen	0.1
Phoenix	PSI/APGen	0.3
MER (prime)	SAP/APGen/Constraint Editor	0.5
MER (extended)	Maestro/APGen/Constraint Generator	0.5
MSL (prime)	MSLICE	1
MSL (extended)	MSLICE	0.5

Cost Comparison of Planning Software (cont.)

- The large discrepancy in cost can be attributed in large part to incorporating lessons learned from past missions
- Additionally, InSight makes use of the multi-mission RAVEN and APGen software, which reduces the need for a new modeling or visualization tool, unlike MSL
- Although Phoenix and MER also use APGen, both missions designed their own resource display tools
- MER has several tools for modeling, plan views, and command sequence generation due to late changes and overhauling the planning software after landing on Mars

Conclusion

- Each JPL mission requires software to accomplish several basic planning functions
- By taking advantage of multi-mission tools, and designing an architecture which makes use of lessons learned, missions can develop capable software for a fraction of the cost
- InSight has done this to great success, creating software which has many of the same features of the other Mars missions with limited development and funding

Backup slides

Cost Comparison Details

- InSight cost includes development for the InSight APGen adaptation, SPImaster, helper scripts, and science planning processes, both before the hiatus and after, leading up to landing on Mars. The cost is a projection maintaining current development estimates until landing.
- Phoenix cost includes development of the Phoenix APGen adaptation, helper scripts, Excel macros, and PSI GUI for science planning. PSI development overlaps with Maestro and MSLICE funding, so it is assumed that for the period of time where all three were in development, there was an even split between them.
- MER prime mission cost includes an estimate of SAP, the MER APGen adaptation, Constraint Editor, helper scripts and the skeleton plan excel tool. This number is difficult to estimate, and is based on a rough approximation of the science planning development in the years leading up to the prime mission.
- MER extended mission is based on the continued development staffing over the course of the 14-year extended mission. This includes an estimate of Maestro development where there was overlap with PSI and MSLICE development, making the assumption that the effort was split evenly between the three missions during this time.

Cost Comparison Details (cont.)

- MSL prime mission cost includes an estimate of MSLICE development over the several years before prime mission. This number includes an image processing tool in MSLICE, but does not include the timeline view, which was developed by NASA's Ames Research Center. The activity dictionary development in MSLICE is also not being included in this estimate, but the table view and sequence generation tool are included. The overlap in development between MSLICE, PSI and Maestro is assumed to be an even split between the three missions.
- MSL extended mission cost includes an estimate of MSLICE, helper scripts, and activity dictionary development during the 6-year extended mission. This number does not account for any additional work on the MSLICE timeline view done by NASA's Ames Research Center.
- Cost estimates are based on the amount of development support and length of development. The dollar amounts being compared use estimates of developer costs in 2018.